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Solar-Assisted Combination Grain Drying:

An Economic Evaluation

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ABSTRACT

A solar-assisted combination grain drying system could result in a 53-percent savings in fossil fuel under optimum conditions. It must be integrated into the planned harvest schedule and other farm energy needs for profitable results. Savings under the most favorable conditions studied showed a 6.6-percent return on investment. Solar collectors costing more than $10 per square foot will likely find little acceptance in a combination drying system at current fossil fuel prices.

Keywords: Grain drying, Solar energy.

PREFACE

This study was conducted in cooperation with the Science and Education Administration, Agricultural Research, U.S. Grain Marketing Research Laboratory, Manhattan, Kans.

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SUMMARY

The major savings associated with a solar-assisted grain drying system are related to reduced investment costs under certain assumptions concerning collector-to-bin size ratios and multiple-use rates. Combination drying has wide geographic application for drying high-moisture grain.

A solar-assisted combination grain drying system compared with a conventional high-temperature drying system could result in a 53-percent savings in the use of liquified petroleum gas (LPG). However, the solar-assisted system requires a sizable increase in electricity use. In the long run, the economic savings will depend on relative escalation rates of electricity and LPG prices.

The partial-budgeting analysis used in this study shows that a solar-assisted combination system, assuming a solar collector costing $4 per square foot, could result in economic savings at most multiple-use rates for all collector-to-bin ratios. Savings under the most favorable conditions, high multiple-use rate and low collector-to-bin size ratio, amount to the equivalent of a 6.6-percent return on investment.

Single-purpose systems are seldom economically feasible even when low-cost, homemade collectors are assumed. However, if more than one use can be found for a homemade collector, then solar energy could be used in a combination drying system and over a wide range of collector-to-bin size ratios. The system would be economically feasible only at high multiple-use rates and low collector-to-bin size ratios at current commercial collector costs--$15 to $20 per square foot. However, the system may become economically feasible assuming 50-percent multiple-use rates and less than 1:1 collector-to-bin size ratios if commercialization lowers the cost of collectors to $10 per square foot.

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INTRODUCTION

Farmers, grain dryer manufacturers, and the Government are seeking methods of reducing energy requirements and costs of grain drying. Farmers may be able to change their current grain drying practices, thus reducing their use of liquified petroleum gas (LPG) and natural gas in this era of fuel shortages. Most changes will be timed to coincide with replacement of current grain drying equipment or related to expansion of existing systems. However, there are some changes that can be made in present practices. Some alternative strategies may include more infield (natural) drying, more efficient management of present systems, and the use of new or mixed systems. 1/ Combination drying is a mixed system.

This study shows the savings gained by using a solar-assisted combination grain drying system for drying corn. The study also shows break-even points for several alternative management strategies. The results should help farmers decide whether or not to invest in a solar collector.

BACKGROUND

Four major grain drying systems are conventionally used: (1) high-temperature, high-airflow dryers--usually batch or continuous-flow dryers operated outside a grain bin; (2) medium-temperature, medium-airflow inbin drying; (3) low-temperature inbin drying; and (4) natural air drying--high airflow.

1/ The grain drying industry is attempting to design more energy-efficient, conventional-type crop dryers.

Two hybrid systems are frequently used also. They are dryeration and combination drying. The term *dryeration* comes from the words drying and aeration. 2/ Dryeration involves a combination of high-speed, high-temperature drying, and slow cooling. Instead of cooling the grain in the dryer by shutting off the heat and running the fan until the grain is cooled, the grain is discharged from the dryer while still hot and carrying some excess moisture (usually 1 to 3 points and 100° to 120° F). The hot grain is put into a cooling bin and steeped 4 to 6 hours, then cooled by use of normal aeration practices.

Utilization of the dryeration principle gives the farmer more bushel-per-hour capacity from a dryer. The capacity of a dryer can be increased more than 60 percent if it is used for heat only. For example, the drying capacity for shelled corn may be increased as follows:

	Bushels per hour
Full heat only, 25 percent to 15 percent	207
Dry and cool, 25 percent to 15 percent	128
Increase	79

A dryeration system is workable under satisfactory drying conditions. However, in certain areas and in some years, aeration may not be sufficient to finish the drying process, and some supplemental heat may be needed.

Combination drying is an especially useful drying method in the South where the ambient air is warm and humid, and in the North where the growing season is short. The term *combination* refers to the combined use of a high-temperature, high-airflow system and a low-temperature, in-bin drying system. Corn, for instance, may be placed in a batch or continuous-flow dryer and dried to about 20-percent moisture. Then, the warm grain may be moved to a drying bin equipped with a fan and heater. The drying bin may be equipped with a solar collector instead of a heater in a combination drying operation.

Combination drying, the system studied in this report, offers the same advantage as dryeration by increasing drying system capacity. It enables farmers to dry grain in all weather conditions. However, since combination drying

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2/ B.A. McKenzie, and others, Dryeration--Better Corn Quality with High Speed Drying, AE-72, Cooperative Extension Service, Purdue University, Lafayette, Ind., undated.

includes a slow method, farm grain bins must serve both as drying and storage facilities. Thus, a fan and the low-temperature heat source must be attached to each bin.

The combined speed of the system makes it an appropriate technology for large-sized grain farms, even though combination drying couples a slow-drying method with a fast-drying method. By contrast, a totally low-temperature grain drying system, one relying on natural air or solar energy, may be more suitable for smaller farms.

SYSTEM DESIGN

A 30,000-bushel drying system is assumed in this study. This system is suitable for a farm harvesting 300 acres of corn, assuming a 100-bushel yield per acre. The average daily harvest could be 2,000 bushels, if the allowable harvest time is spread over 15 days. A dryer capacity of 200 bushels per hour would be needed, based on a 10-hour harvest day.

Three 10,000-bushel bins, each 27 feet in diameter and 22 feet high, are assumed. Each bin contains 513 square feet of floor area. It is preferable that these bins have a reasonably wide diameter when employing a low-temperature, solar-drying method, and that daily fill depth be kept to a minimum. However, by placing corn in the bin at an 18- to 20-percent moisture level, the low-temperature heat produced by a solar collector should be sufficient in most cases to finish the drying process without spoilage, even in small-diameter bins.

Grain bins and dryers may be combined into any size system needed and are not limited exclusively to corn. The optimum number of grain bins may be about five for larger systems. This allows the farmer to place each day's harvest in a different bin, assuming the harvest is conducted 5 days per week. Thus, the farmer would actually have a batch-in-bin system with a week between batches placed in each bin.

A high-temperature, batch-type dryer with capacity to dry (heat only) 200 bushels of corn per hour, removing 5 points of moisture, represents a capital investment of approximately $9,000 (1979 dollars). This is the dryer type assumed for the solar-assisted grain drying system. It would be used at near-full capacity at the beginning of the harvest period and at a lower capacity as the harvest progresses and the moisture content decreases. It would be capable of drying corn with 25- to 27-percent moisture--the level at which corn harvest typically begins in the United States. A similar dryer large enough to dry and cool 200 bushels of corn per hour, removing 10 points of moisture, would cost approximately $16,000 (1979 dollars).

A portable solar collector is assumed. The significance of this assumption is related to other uses that may be found for collectors when they are not being used to dry grain. It is important to construct or purchase collectors that may be moved, since other farm uses may not be in the immediate vicinity of the grain bins. Portable collectors should not exceed dimensions of 12 x 48 feet in most cases, considering the need for maneuverability through farm gates and positioning for alternative uses. In fact, a more manageable size would be 12 x 24 feet, with two collectors hooked in tandem.

In this study, four use rates for grain drying are assumed: 100, 75, 50, and 25 percent. A 75-percent use rate means the solar collector is used three-fourths of the time for grain drying and one-fourth of the time for another use. Less than full fixed cost is charged to the grain-drying function when the solar collector is not used full-time for grain drying.

A homemade flat-plate solar collector having a 10-year life expectancy is assumed. A 10-year life is possible when fiberglass cover plates are used. The life of a homemade collector covered with polyethylene may be shorter.

A commercial flat-plate collector having a 20-year life expectancy is also used in the analysis. Commercial collectors have an advantage of longer life because more durable materials are used in their construction.

Three ratios of collector surface-to-bin floor area are used in this study: 1:1, 3/4:1, and 1/2:1. Collector surface requirements vary by climatic area and by assumptions concerning the role of the low-temperature collector. Generally, a higher ratio of solar collector surface-to-bin floor area is needed in humid areas, or if solar energy is expected to play a larger role in drying than is assumed in this study. A lower ratio of collector surface-to-bin floor area is necessary for a higher temperature, more efficient, commercially built collector than for a lower temperature, less efficient, homemade collector.

A capital investment cost for homemade collectors is estimated at $4 per square foot for part of the analysis, and at ranges from $3 to $5 per square foot for part of the analysis. Two prices are assumed for the commercial collector. First, a $10-per-square foot collector is used. This price is below current levels, but it is assumed to represent the approximate cost of commercial collectors once mass production begins. Second, a $15-per-square foot collector is used, representing the lower end of the current price range of commercial collectors.

For each collector, a constant additional investment of $1,800 is assumed for fans (7.5-horsepower centrifugal), transition(s), and other related equipment. 3/ Thus, an additional investment of $5,400 is required for the three collectors necessary to service the three drying bins assumed in this study.

The following fuel consumption estimates are used: 4/

Moisture reduction (percent wet basis)	
25 to 15	0.15 gallon LPG per bushel
	.14 kWh electricity per bushel
25 to 20	.07 gallon LPG per bushel
	.07 kWh electricity per bushel

Electricity used for operating the solar collector fan is assumed to be 0.5 kWh per bushel. The price of LPG is assumed to be 35 cents per gallon. The price of electricity is assumed to be 5 cents per kWh.

RESEARCH METHODOLOGY

Fuel savings associated with the solar-assisted combination grain drying system are not large; thus, two methods--payback and life-cycle costing--although common measures of economic feasibility in the solar field, are not used for this study. Instead, two traditional

3/ Costs of the grain drying storage bins are not included in this analysis.

4/ Adapted from estimates shown in A Guide to Energy Savings for the Field Crops Producer, U.S. Department of Agriculture and Federal Energy Administration, June 1977. Adjusted for recently designed energy-saving methods.

techniques--partial-budgeting and break-even analysis--are used. It is possible to determine the conditions under which a combination system is preferable to a conventional grain drying system with these economic tools.

Briefly described, the two methods are:

Partial budgeting--Measures changes in costs and returns associated with the decision to replace a high-temperature conventional drying system with a solar-assisted combination system.

Break-even analysis--Requires cost levels for selected solar-assisted combination systems to be economically feasible--lower in cost than a conventional grain drying system.

Partial Budgeting

Partial budgeting is a tool most commonly used on problems associated with the adoption of new or additional technology, equipment, or structures that affect only one segment of the total business. A partial-budgeting analysis deals only with changes in costs and returns, not with total cost and total returns. 5/

Two things farmers must look at when they consider using a solar collector for combination grain drying are changes in investment and fuel (energy) requirements. The partial-budgeting procedure enables decisionmakers to predict their immediate net gain or loss should a certain decision be made.

5/ Northeast Farm Management Extension Committee, Budget Procedures for Analyzing Farm Adjustments, a Northeast Regional Pub., rev. ed., 1967.

Break-even Analysis

A break-even analysis complements the partial-budgeting technique. This method is also used to make comparisons by collector cost. This analysis provides the decisionmaker with quick visual information. A simple formula for computing break-even points is used:

$$\frac{\text{Fixed cost of conventional system}}{\text{Number of bushels}} +$$

Energy cost of conventional system per bushel +

Other operating costs of conventional system per bushel =

$$\frac{\text{Fixed cost of combination system}}{\text{Number of bushels}} +$$

Energy cost of new system per bushel +

Other operating costs of combination system.

Conventional High-temperature System

Sole use of the high-temperature system would result in the following fuel consumption and investment assumptions: 6/

Situation

30,000 bushels of 25-percent moisture corn dried to 15 percent.

Energy requirements

0.15 gallon LPG x 30,000 bushels	=	4,500 gal.
0.14 kWh electricity x 30,000 bushels	=	4,200 kWh

Energy dollars

4,500 gallons LPG x 35 cents per gallon	=	$1,575
4,200 kWh electricity x 5 cents per kWh	=	210
Total		$1,785

The investment requirement for the conventional high-temperature system is assumed to be $16,500. Annual interest on investment at 10 percent equals $1,650.

6/ The costs and other assumptions made in this study will vary by area, size, and type of dryers considered.

Solar-assisted Combination System

Partial use of the high-temperature system would result in the following fuel consumption and investment assumptions:

Situation

30,000 bushels of 25-percent moisture corn dried to 20 percent.

Energy requirements

0.07 gallon LPG x 30,000 bushels	=	2,100 gal.
0.07 kWh electricity x 30,000 bushels	=	2,100 kWh

Energy dollars

2,100 gallons LPG x 35 cents per gallon	=	$735
2,100 kWh electricity x 5 cents per kWh	=	105
Total		$840

Energy savings

Complete high-temperature system	=	$ 1,785
Partial high-temperature system	=	840
Total net fuel savings		$ 945

Capital investment savings

Batch type dryer for drying and cooling (200 bushels per hour capacity)	=	$16,500
Batch type dryer for drying only (200 bushels per hour capacity)	=	9,000
Net capital investment savings	=	$ 7,500, and
Annual interest on investment at 10 percent	=	$ 750

Use of a solar collector and related equipment would result in the following fuel consumption and investment assumptions:

Situation

30,000 bushels of 20-percent moisture corn dried to 15 percent.

Energy requirements

0.5 kWh electricity x 30,000 bushels = 15,000 kWh

Energy dollars

15,000 kWh electricity x 5 cents per kWh = $750

Capital investment (solar)

Item	Collector-to-bin ratio		
	1:1	3/4:1	1/2:1
Solar collector 7/	$ 6,156	$ 4,617	$ 3,078
Related equipment	+ 5,400	+ 5,400	+ 5,400
Total	$11,556	$10,017	$ 8,478

Capital investment (solar-assisted combination system)

Percentage use rate	Collector-to-bin ratio		
	1:1	3/4:1	1/2:1
100	$20,556	$19,017	$17,478
75	17,667	16,513	15,358
50	14,778	14,008	13,239
25	11,889	11,504	11,120

If decision is made to change to a solar-assisted combination grain drying system, the net energy result would be:

Reduced energy requirements (related to use of conventional dryer heat only)

LPG	2,400 gallons
Electricity	2,100 kWh

Added energy requirements (related to use of fan on solar collector)

Electricity	15,000 kWh

Net energy situation

LPG	-2,400 gallons
Electricity	+12,900 kWh

7/ Collector size would vary slightly from the prices shown because of common lumber dimensions.

ANALYSIS

In this section, the partial-budgeting and break-even analysis tools are used to evaluate the economic potential of a solar-assisted combination grain drying system.

Partial Budgeting

Partial budgeting is used to show the net economic results for three collector-to-bin size ratios and for four multiple-use rates. This analysis also assumes a solar collector cost of $4 per square foot.

Reduced returns

None

Reduced costs

Annual savings of interest on investment	= $ 1,650
Net fuel savings	= 1,785
Subtotal	$ 3,435

Added returns 8/

None

8/ One advantage of this combination drying system, although not considered in this study, is the suppression of aflatoxins by quickly reducing total moisture content with a high-temperature dryer. Aflatoxins can sometimes be spread before the grain is dried when the low-temperature, slow drying method is used.

Added costs

	Percentage multiple-use rates			
	100	75	50	25
	Dollars			
Largest collector-to-bin ratio (1:1):				
Electricity for solar drying	750	750	750	750
Electricity for high-temperature drying	105	105	105	105
LPG for high-temperature drying	735	735	735	735
Interest on capital investment at 10 percent	2,056	1,767	1,478	1,189
Subtotal	3,646	3,357	3,068	2,779
Annual savings	-211	+ 78	+367	+656
Medium collector-to-bin ratio (3/4:1):				
Electricity for solar drying	750	750	750	750
Electricity for high-temperature drying	105	105	105	105
LPG for high-temperature drying	735	735	735	735
Interest on capital investment at 10 percent	1,902	1,651	1,401	1,150
Subtotal	3,492	3,241	2,991	2,740
Annual savings	- 57	+194	+444	+695
Smallest collector-to-bin ratio (1/2:1):				
Electricity for solar drying	750	750	750	750
Electricity for high-temperature drying	105	105	105	105
LPG for high-temperature drying	735	735	735	735
Interest on capital investment at 10 percent	1,748	1,536	1,324	1,112
Subtotal	3,338	3,126	2,914	2,702
Annual savings	+ 97	+309	+521	+731

Break-even Analysis

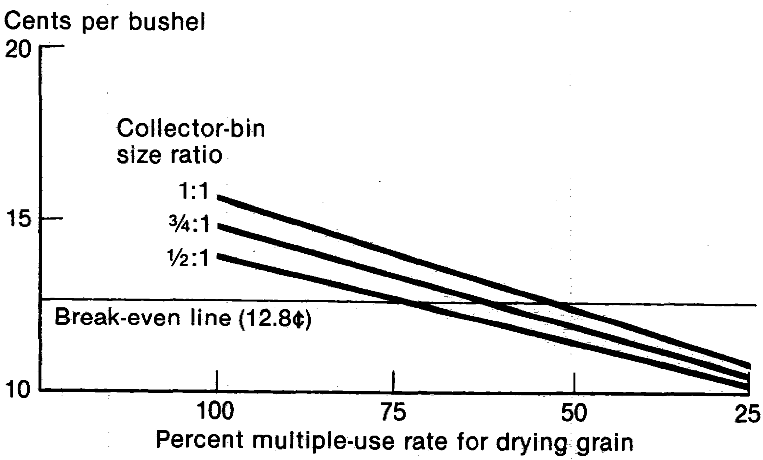
The break-even analysis, like the partial-budgeting technique, shows the importance of multiple-use considerations. A solar-assisted combination system was found to be economically feasible (assuming collectors costing $4 per square foot) at all size ratios only at multiple-use rates of 50 and 25 percent (fig. 1). Farmers in areas where a 1/2:1 collector-to-bin size ratio is feasible may also be economically ahead to use a solar-assisted combination system.

A single-purpose (dedicated) collector is likely to be the first type considered by most farmers, since they are more accustomed to using dedicated rather than multipurpose equipment, although a multiple-use collector is least costly. Also, some early innovators may be farmers specializing in grain production.

Figure 2 shows that a solar-assisted combination grain drying system should not be considered, even at the lowest collector cost level, if there are no other farm uses for the collector. Presently, a dedicated system is not competitive with a conventional system at any collector-to-bin size ratio.

Figure 1

Break-Even Points Between Owning a Conventional High-Temperature Grain Dryer and a Solar-Assisted Combination Drying System Assuming Three Solar Collector-Bin Size Ratios at $4 Per Square Foot for a Solar Collector



Solar-assisted combination drying costs compare most favorably with conventional drying costs when both low collector costs and multiple uses are possible. Figure 3 illustrates a situation in which the solar collector is used only half the time for grain drying. This assumes at least one other farm use. At this multiple-use rate, a solar-assisted combination grain drying system was found to be lower in cost than the conventional system for all three homemade collector cost levels and at each collector-to-bin size ratio. The break-even analysis also shows the importance of multiple uses when considering commercial collectors. At $10 to $15 per square foot, a solar-assisted combination system incorporating a commercial collector was found to be economically competitive with a conventional system when applied to nongrain drying uses at least 75 percent of the time.

CONCLUSIONS

It is technically feasible for solar collectors to replace fossil fuel or electric heat in a combination drying system. However, there are several factors that farmers must consider before adopting a solar-assisted combination

Figure 2

Break-Even Points for a Dedicated Solar-Assisted Combination Grain Drying System Assuming $3 Per Square Foot for a Solar Collector

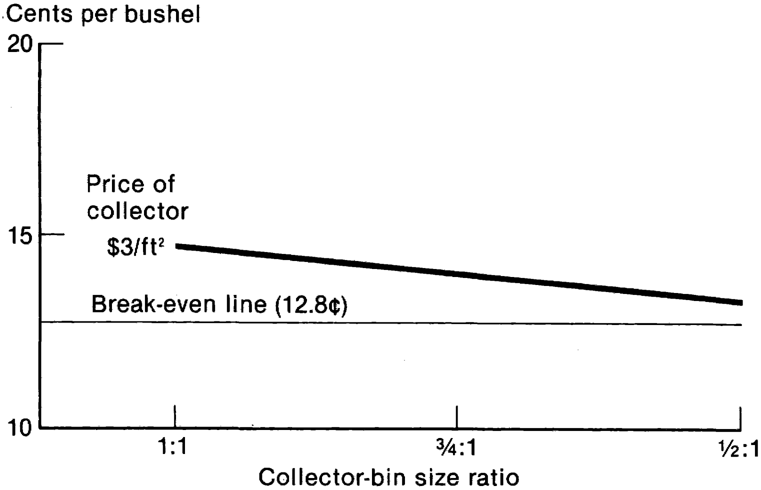
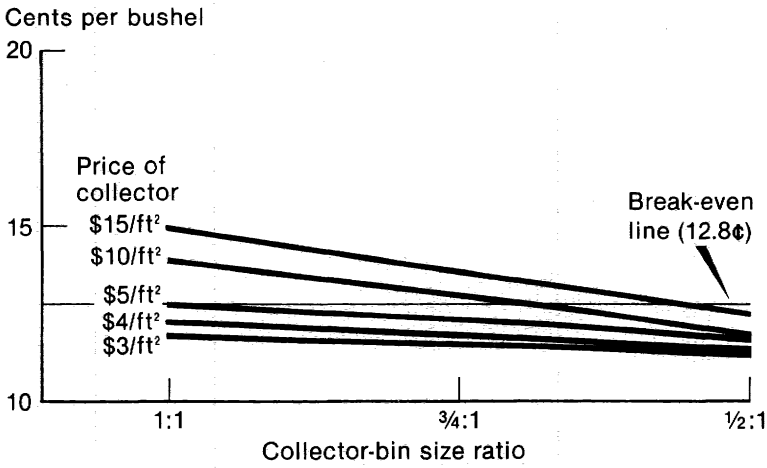


Figure 3

Break-Even Points for Solar-Assisted Combination Grain Drying System Assuming a 50-Percent Multiple-Use Rate and Five Prices of Solar Collectors Per Square Foot of Surface



grain drying system. Plans to change a grain drying system must be integrated into the existing farm management system. Specifically, such plans must be closely related to the expected harvest rate, to the present grain drying system, and to other farm energy needs. Furthermore, any plan must be profitable. If solar collectors are to be used by farmers, they must be efficient, preferably reducing total operating cost as well as conserving fuel. The farmer is not likely to be motivated to make the change if the proposed change uses less fuel but results in a high capital investment to do so. At current conventional fuel costs, solar collectors costing above $10 per square foot may not find wide acceptance in combination drying systems.

The costs and returns of other associated uses should be considered before a decision is made to use a solar collector as part of a combination grain drying system. Other farm uses of a solar collector may result in more or less savings than grain drying. If they result in more savings, the joint returns from using solar energy may make a solar-assisted combination grain drying system more attractive than this study suggests and vice versa. Regardless, it is important to know that, under some conditions, fossil fuels can be saved and the cost of drying grain can be reduced by using solar energy in combination drying.

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